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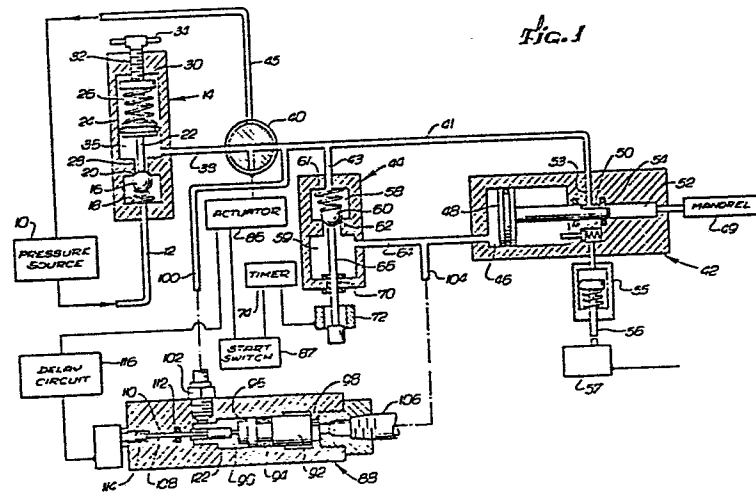
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⑤④ **An apparatus for forming leak-proof joints between tubes and tube sheet.**

⑤⑦ In an apparatus for forming leak-proof joints between tubes and a tube sheet by the internal application of hydraulic swaging pressure, the flow of relatively low pressure fluid from a pressure source (10) to an intensifier (42) is permitted or interrupted by a control valve (40). During a prefill period, a prefill valve (44) causes the low pressure fluid to bypass the low pressure input side of the intensifier and to flow directly to the high pressure side and then to a mandrel (49). After a predetermined period to allow prefilling of the mandrel and associated tube portions, the low pressure fluid is caused to enter the low pressure side of the intensifier which operates to increase the pressure in the mandrel during a swaging period.



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"An apparatus for forming leak-proof joints between tubes and a tube sheet."

10 The present invention relates to an apparatus for forming leak-proof joints between tubes and a tube sheet. More specifically the invention relates to hydraulic swaging in the formation of leak-proof joints between tubes and a tube sheet, and, more particularly, to the automated regulation of hydraulic fluid flow.

15 In the construction of a typical heat exchanger, a large number of tubes must pass through a tube sheet, and substantially leak-proof joints must be formed between the tubes and the sheet. When, for example, the heat exchanger forms part of a nuclear power plant, particularly high standards of reliability are required. In such applications, the tube sheet, which is made of steel as much as two-feet (0.6m) thick, separates heated
20 radio-active nuclear material from a non-radio-active cooling fluid, such as water. It is apparent that even very small leaks between these heat exchanger zones are intolerable. A large number of such joints are included in a single heat exchanger, and each joint must meet the same high standards of reliability.
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Although roller swaging has been used to form tube and tube sheet joints, hydraulic swaging has proven to be superior. Hydraulic swaging pressures as high as 50,000 p.s.i. (345 MPa) can be uniformly applied
30 throughout a selected axial portion of the tube. EP-A-0066871 discloses one apparatus for supplying and controlling hydraulic swaging pressure, and that application is hereby incorporated by reference herein. EP-A-0066871 describes apparatus that permits the automation, to a considerable extent, of the formation of tube/tube sheet joints, reducing
35 the possibility of human error.

In most previously known hydraulic swaging apparatus, a mandrel is inserted into the portion of the tube within the tube sheet, and axially separated seals carried by the mandrel define a pressure zone within which the swaging pressure is to be applied. Pressurized fluid is introduced through the mandrel into a small annular space between the mandrel and
5 the tube to expand the tube radially. Typically the pressure is first generated by a pump and then multiplied by an intensifier before it is supplied to the mandrel.

A skilled worker must insert the mandrel in each tube individually
10 and cause pressure to be applied by the operation of a control valve. Once the valve has been opened, sufficient time must be allowed for the pressure to reach the desired level. For best results, the pressure should be held at that level for a finite time period typically of the order of magnitude of two seconds. The optimum swaging pressure and dwell time varies,
15 depending on the specific characteristics of the tube and the tube sheet.

The intensifier is capable of expelling into the mandrel only a relatively small quantity of high pressure fluid before the pistons reach the ends of their strokes. Thus, the pressure generated by the intensifier may
20 be lost in filling the mandrel and the joint may not be properly formed.

Ideally, the swaging apparatus should be automated to reduce the possibility of human error. A primary objective of the present invention is to provide a swaging apparatus for use in forming tube and tube sheet
25 joints which is automated to ensure, with a high degree of reliability, that undue amounts of the pressure generated by the intensifier are not wasted in filling of the mandrel before the increased pressure from the intensifier is applied to create the joint. A still further objective is the provision of such an apparatus that is highly efficient and permits each
30 of many joints to be formed consistently within a minimum time period.

Accordingly, the invention provides an apparatus for forming leak-proof joints between tubes and tube sheets by the application of hydraulic swaging pressure within the said tubes, which apparatus comprises pressure
35 source means for supplying a hydraulic fluid under relatively low pressure; mandrel means adapted to be inserted into a said tube for delivering

pressurized hydraulic fluid to the tube; intensifier means for increasing the pressure of said fluid to a pressure suitable for swaging, said intensifier means having a low pressure input side and a high pressure output side connectable to said mandrel means; and prefill means for causing said low pressure fluid to flow first to said mandrel during a prefill period, thereby prefilling said mandrel and at least a portion of said tube, and thereafter causing said low pressure fluid to flow to said input side of said intensifier to commence a swaging period.

Desirably, the prefill means comprises a valve means.

Preferably, the output side of the intensifier is connectable to said pressure source means to receive low pressure fluid directly therefrom. One preferred prefill means comprises prefill valve means through which said pressure source means is connectable to the input side of said intensifier means, said prefill valve means being switchable from a first condition, in which the flow of low pressure fluid to said input side is blocked during a prefill period allowing the mandrel to be prefilled by the supply of low pressure fluid through said output side, and a second condition in which the flow of said low pressure fluid to said input side of the intensifier is permitted during a swaging period, thereby causing said intensifier means to provide high pressure fluid to said mandrel after said mandrel and tube have been prefilled at said low pressure.

Desirably prefill timer means is provided to cause the prefill means to terminate said prefill period after a predetermined time.

The prefill valve may include a seat and a ball urged against the seat by the low pressure fluid, the ball being forced off the seat during the swaging period.

Preferably, the intensifier includes blocking means for blocking the flow of low pressure fluid to the output side. It may include a prefill inlet and a piston, which may define a channel that cooperates with the inlet. The piston blocks the inlet after the swaging period begins.

Conveniently, a pressurization sensor is included in the apparatus.

The sensor receives inputs from points that are upstream and downstream of the prefill valve and terminates the swaging period after a predetermined comparative pressure relationship between these inputs has been reached.

In order that the invention may be more readily understood and so
5 that further features thereof may be appreciated, an apparatus in accordance with the present invention will now be described, by way of example, with reference to the accompanying drawing, which is a partially diagrammatic illustration of an apparatus constructed in accordance with the present invention, a pressure reduction valve, prefill valve, intensifier,
10 and pressurization sensor being shown in transverse cross-section.

Referring to the drawing, an apparatus, constructed in accordance with the present invention comprises a pressure source 10 by which a hydraulic fluid, such as water, is initially pressurized. Suitable pressure
15 sources of conventional construction include a pump and a reserve tank (not shown separately in the drawing). The fluid exiting from the pressure source 10 is, however, at a relatively low pressure considerably below that required for hydraulic swaging.

20 From the pressure source 10, fluid is supplied by a line 12 to the input side of a pressure reduction valve 14. This valve 14 includes, at its bottom end, a ball 16 held by a ball spring 18 against a seat 20 to keep the valve closed. A counter-force is applied from above by a rod 22 that projects downwardly from a piston 24, the piston being urged downwardly by a
25 coil spring 26 so that the force of the piston 24 tends to unseat the ball 16 and allow fluid to flow past the seat 20 through an orifice 28. The top of the coil spring 26 presses against a retainer 30 which is adjustably positioned at the top by a threaded member 32 that is integrally formed with an external handle 34. Thus, by turning the handle 34 the retainer
30 30 may be lowered. In this way, the upward force on the piston 24 required to raise the piston to the extent that the ball 16 closes against the seat 20 is increased.

Although the adjustable pressure reduction valve 14 is shown in its
35 closed position with the ball 16 against the seat 20, the force of the coil spring 26 will overcome the ball spring 18 and push the ball 16 off the



seat 20 when the apparatus is depressurized. However, the passage of pressurized fluid into a chamber 36 above the seat 20 and below the piston 24 tends to overcome the force of the coil spring 26, allowing the ball 16 to rise closer to the seat. The effect of the counteracting forces of the pressure in the chamber 36 and of the coil spring 26 is to retain the ball 16 in a relatively quiescent position in which the output pressure of the valve 14 is reduced to a level corresponding to the position to which the retainer 30 is adjusted.

Low pressure hydraulic fluid exits from the chamber 36 by a line 38 leading to a control valve 40. With the control valve 40 in its open or flow-through position, as shown in the drawing, the pressurized fluid can flow through a line 41 to an intensifier 42 and through a branch line 43 to a prefill valve 44. In a second position, the control valve 40 permits return flow to the pressure source 10 through a line 45.

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The function of the intensifier 42 is to elevate the pressure of the hydraulic fluid to the pressure required for swaging. It has an input side with a low pressure cylinder 46 in which a relatively large first piston 48 can reciprocate. A high pressure output side connected to a mandrel 49 includes an axially aligned rod-like smaller second piston 50, the two pistons moving together. The opposite end of the smaller piston rides in a high pressure cylinder 52.

A prefill inlet 53 in the high pressure cylinder 52 can receive low pressure fluid from the line 41 when the smaller piston 50 is withdrawn from the high pressure cylinder to the maximum extent (as shown in the drawing). A channel 54 extending axially along a portion of the surface of the smaller piston 50 permits this inflow of low pressure fluid. As the piston 50 moves into the cylinder, however, it serves to block the prefill inlet 53. An air valve 55 is arranged to be actuated by the large piston 48 in the event that a lack of swaging resistance causes the larger piston to travel the full length of the low pressure cylinder 46. In that event, the air valve 55 causes an external piston 56 to operate a no-swage switch 57, the significance of which will be explained below.

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The prefill valve 44 includes two chambers 58 and 59. The first

chamber 58 is connected to the branch line 43, which supplies low pressure fluid when the control valve 40 is open, and contains a ball 60 urged by a ball spring 61 against a seat 62 to keep the valve 44 closed. The second chamber 59 is connected by a line 64 to the low pressure cylinder 46 of the intensifier 42, and includes a rod 66 aligned with the ball 60. The
5 rod 66 is positioned so that it acts against the ball 60 at one end and cooperates with a solenoid 72, that is positioned external of the valve 44, at its other end. A seal 70 encircles the rod 66 to prevent leakage of swaging fluid when the prefill valve 44 is open. Actuation of the solenoid 72, responsive to a prefill timer 74, causes the rod 66 to lift the ball 60,
10 and thus opens the valve 44 allowing fluid to pass through the valve to the low pressure cylinder 46.

Although each cycle of operation of the apparatus is commenced by a manually initiated signal from a start switch 87, a cycle is terminated
15 automatically by a signal to a control valve actuator 86. This actuator 86 is, in turn, indirectly responsive to an electrical signal originated by a pressurization sensor 88. A cylinder 90 within the sensor 88 contains a piston 92 which can reciprocate slidably within the cylinder under the influence of the fluid pressure acting on it. The piston 92 is surrounded
20 by a pressure seal 94. Since the cylinder 90 is longer than the piston 92, the piston can define a first chamber 96 at one end thereof and a second chamber 98 on the opposite side. The size of each of the chambers 96 and 98 depends upon the axial position of the piston 92. [In the drawing, the piston 92 has moved all the way to one side of the chamber 90, defining
25 the largest possible chamber 96].

To influence the position of the piston 92, a first pressure line 100 is connected to the line 41 that connects the control valve 40 to the prefill valve 44. The pressure line 100 supplies this pressure from a position
30 upstream of the prefill valve 44 to a radial inlet port 102 that communicates with the first chamber 96 of the sensor 88. A second pressure line 104 runs from the line 64, by which pressurized fluid flows from the prefill valve 44 to the intensifier 42, to an axial inlet port 106 at the end of the pressurization sensor 88 opposite to the end with the radial inlet port
35 102 so that the second pressure line 104 communicates with the second chamber 98 of the sensor 88.

Extending from the first chamber 96 and away from the piston 92 is a slideway 108 in the form of a radially-centered axial bore that contains a rod 110 attached to the piston for movement therewith. A seal 112 encircles the rod 110 within the slideway 108. At the end of the slideway 108 remote from the piston 92 is an electrical switch 114 operable by
5 the rod 110. When closed, the switch 114 delivers an electrical signal to an adjustable time delay circuit 116 from which the signal is supplied to the control valve actuator 86, thereby causing the termination of the swaging cycle.

10 The operation of the apparatus will now be explained. When the apparatus is not in use, the control valve 40 occupies a position that is ninety degrees counter-clockwise from that shown in the drawing. In this position, fluid is prevented from flowing from the pressure reduction valve 14 to the intensifier 42 and the prefill valve 44. The line 41 by
15 which fluid can be supplied to the intensifier 42 and the prefill valve 44 is connected to a return line 45 that permits the intensifier to be depressurized. However, pressurized fluid from the pressure reduction valve 14 does flow through the line 38 up to the control valve 40.

20 The user of the apparatus manually operates the start switch 87, signalling the control valve actuator 86, to cause the control valve 40 to move to the position shown in the drawing and allowing the pressure reduction valve 14 to communicate with the prefill valve 44 and the high pressure cylinder 52 of the intensifier 42 through the lines 43 and 41
25 respectively. During this period, fluid flows into the line 100 leading to the first chamber 96 of the sensor 88. Accordingly, the first chamber 96 is pressurized, whereas no pressure is applied to the second chamber 98 of the sensor 88. The piston 92, therefore, moves as far as permitted to one end of the cylinder 90 (as shown in the drawing).

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The fluid entering the line 41 fills the high pressure cylinder 52, the mandrel 49 and the volume of the tube (not shown) with which the mandrel communicates. After a predetermined period, the prefill timer 74 sends a signal which activates the prefill valve solenoid 72 and causes the prefill
35 valve 44 to open by moving the rod 66 to unseat the ball 60. The period

of delay measured by the timer 74 should be determined empirically for a particular swaging apparatus and its intended use.

Once prefilling is complete, fluid enters the second chamber 59 of the prefill valve 44 and passes through the line 64 into the first cylinder 46 of the intensifier 42. The larger piston 48, being exposed to the same pressure, easily overcomes the resistance of the smaller rod-like piston 50 and the two pistons 48 and 50 begin to move together so as to expand that part of the first cylinder 46 which communicates with the line 64.

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Once the cut-away portion 54 of the rod-like piston 50 passes the inlet 53, the high pressure cylinder 52 no longer communicates with the line 41 from the pressure control valve 40, thus beginning the swaging period of the cycle. Thereafter, movement of the two pistons 48 and 50 multiplies the low pressure applied to the first piston 48 and the resulting high pressure is supplied to the mandrel 49.

As the larger piston 48 moves within the first cylinder 46 of the intensifier 42, pressurized fluid from the line 64 also flows through the line 104 and into the second chamber 98 of the sensor 88. Initially, the pressure in the second chamber 98 of the sensor 88 is less than the pressure in the first chamber 96 and the piston 92 does not move. However, the pressure in the second chamber 98 continues to rise as the prefill valve 44 remains open.

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The effective pressure surface of the piston within the first chamber 96 is reduced due to the presence of the rod 110 which prevents the fluid from acting on the entire surface of the piston 92. Thus, the force applied to the piston 92 in the second chamber 98 will eventually become greater than the force applied to the piston in the first chamber 96. The reduction in the effective pressure surface area of the first end 96 is comparatively rather small. In the preferred embodiment, the effective pressure surface area of the piston end in the first chamber 96 is approximately 95 percent of the surface area of the piston end in the second chamber 98, although this proportion may be varied in accordance with the desired parameters of a particular system.

The exact configuration of the rod 110 of the pressurization sensor 88 is not critical. In this embodiment, the rod 110 has an enlarged portion 122 within the cylinder 90. However, it is the area of the rod 110 as it passes through the seal 112 that represents the actual reduction of the effective piston surface area. Any changes in the cross-section of the rod 110 between the seal 112 and the piston 92 have no significant hydraulic effect.

When the pressure in the second chamber 98 reaches 95 percent of the pressure reduction valve output pressure as applied to the first chamber 96, the piston 92 will move. As it moves, the rod 110 will operate the switch 114 to provide a control signal to the delay circuit 116. Once the delay to which the circuit 116 has been adjusted has expired, the control signal will be supplied to operate the control valve actuator 86, returning the control valve 40 to the position which allows communication with the return line 45, thereby causing the intensifier 42 and the mandrel 78 to be depressurized. The control valve actuator 86, when triggered by the control signal from the delay circuit 116, simultaneously sends a signal to reset the prefill timer 74. The reset signal causes the prefill valve solenoid 72 to lower the piston 66 and allow the rod 68 to return the ball 58 to its seat 62, thus closing the prefill valve 44 in preparation for the next swaging cycle.

It should be noted that pressurization sensor 88 is operated before the intensifier 42 and the mandrel 78 reach the full output pressure of the pressure reduction valve 14, in this case at 95 percent of that pressure. However, the pressure is rising rapidly at that point and the delay circuit 116 can be adjusted, based on empirical results, to a level that allows full pressure to be reached before the control valve actuator 86 is operated. The delay should, however, be longer than that required merely to reach this maximum pressure. The delay should allow the system to dwell briefly at that maximum pressure for a period sufficient to form the desired optimum joint between the tube and the tube sheet.

The desired swaging pressure can be set by repositioning the retainer 30 of the reduction valve 14. Although the pressure directly adjusted in this way is the output pressure of the pressure reduction valve 14, the

output pressure of the intensifier 42 is always proportional. It is not necessary to make adjustments to the pressurization sensor 88, as this is responsive to the comparative pressures on the output side of the control valve 40 and the input side of the intensifier 42. Thus, the switch 114
5 will always be operated when the intensifier 42 input pressure applied to the second chamber 98 reaches a fixed percentage of the pressure in the first chamber 96. This proportional relationship will hold true for all pressures to which the system might be set.

10 The operation of the no-swage air valve 55 should also be noted. It becomes operational in the event that a tube is not effectively swaged within the tube sheet due to, for instance, a leak downstream of the intensifier 42. Such a leak could occur if, for example, the mandrel 49 were not properly sealed to the surrounding tube surface, in which case
15 pressure would be lost. The absence of pressure resisting movement of the pistons 48 and 50 would quickly cause those pistons to move until the larger piston 48 reached the end of the first cylinder 46, operating the air valve 55 to activate a no-swage indicator (not shown). The operator would thus be made aware of the fact that a proper joint had not been
20 formed.

The features disclosed in the foregoing description, in the following claims and/or in the accompanying drawing may, both separately and in any combination thereof, be material for realising the invention in
25 diverse forms thereof.

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CLAIMS:

1. An apparatus for forming leak-proof joints between tubes and tube sheets by the application of hydraulic swaging pressure within the said tubes, which apparatus comprises pressure source means for supplying
5 a hydraulic fluid under relatively low pressure; mandrel means adapted to be inserted into a said tube for delivering pressurized hydraulic fluid to the tube; intensifier means for increasing the pressure of said fluid to a pressure suitable for swaging, said intensifier means having a low
10 pressure input side and a high pressure output side connectable to said mandrel means; and prefill means for causing said low pressure fluid to flow first to said mandrel during a prefill period, thereby prefilling said mandrel and at least a portion of said tube, and thereafter causing said low pressure fluid to flow to said input side of said intensifier to commence
15 a swaging period.
2. An apparatus according to claim 1, wherein said prefill means further comprises a valve means.
- 20 3. An apparatus according to claim 1 or 2, wherein the output side of the intensifier is connectable to said pressure source means to receive low pressure fluid directly therefrom.
4. An apparatus according to claim 3, wherein the prefill means comprises
25 prefill valve means through which said pressure source means is connectable to the input side of said intensifier means, said prefill valve means being switchable from a first condition, in which the flow of low pressure fluid to said input side is blocked during a prefill period allowing the mandrel to be prefilled by the supply of low pressure fluid through said output
30 side, and a second condition in which the flow of said low pressure fluid to said input side of the intensifier is permitted during a swaging period, thereby causing said intensifier means to provide high pressure fluid to said mandrel after said mandrel and tube have been prefilled at said low pressure.
- 35 5. An apparatus accordingly to any one of claims 1 to 4, further comprising prefill timer means for causing said prefill means to terminate

said prefill period after a predetermined time.

6. An apparatus according to claim 3, 4 or 5, wherein said intensifier means includes blocking means for blocking the flow of said low pressure fluid to the output side of the intensifier after said swaging period has begun.

7. An apparatus according to any one of claims 3 to 6, wherein said intensifier comprises a large piston and cylinder in said input side and a small piston and cylinder in said output side, said pistons being interconnected for cooperative movement; said small cylinder having a prefill inlet for said low pressure fluid that is positioned to be blocked by movement of said small piston during said swaging period.

8. An apparatus according to claim 7, wherein said small piston defines a channel through which said low pressure fluid can flow from said prefill inlet during said prefill period.

9. An apparatus according to any one of claims 2 to 8, wherein said prefill valve means comprises a seat, a ball urged against said seat by said fluid, and means for moving said ball off said seat during said swaging period.

10. An apparatus according to any one of claims 2 to 9, further comprising a pressurization sensor that receives inputs from points upstream and downstream of the prefill valve means and operates to terminate the swaging period after a pre-determined comparative pressure relationship between the inputs has been reached.

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[illegible]

PRESSURE
SOURCE